Proceedings of the 10th Annual Water Distribution Systems Analysis Conference WDSA2008, Van Zyl, J.E., Ilemobade, A.A., Jacobs, H.E. (eds.), August 17-20, 2008, Kruger National Park, South Africa.

PROJECT NEPTUNE: IMPROVED OPERATION OF WATER DISTRIBUTION NETWORKS

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Abstract

Water service providers (WSPs) in the UK have statutory obligations to supply drinking water to all customers that complies with increasingly stringent water quality regulations and minimum flow and pressure criteria. At the same time, the industry is required by regulators and investors to demonstrate increasing operational efficiency and to meet a wide range of performance criteria that are expected to improve year-on-year. Most WSPs have an ideal for improving the operation of their water supply systems based on increased knowledge and understanding of their assets and a shift to proactive management followed by steadily increasing degrees of system monitoring, automation and optimisation. The fundamental mission is, however, to ensure security of supply, with no interruptions and water quality of the highest standard at the tap. Unfortunately, advanced technologies required to fully understand, manage and automate water supply system operation either do not yet exist, are only partially evolved, or have not yet been reliably proven for live water distribution systems. It is this deficiency that the project NEPTUNE seeks to address by carrying out research into 3 main areas; these are: data and knowledge management; pressure management (including energy management); and the associated complex decision support systems on which to base interventions. The 3-year project started in April of 2007 and has already resulted in a number of research findings under the three main research priority areas (RPA). The paper summarises in greater detail the overall project objectives, the RPA activities and the areas of research innovation that are being undertaken in this major, UK collaborative study.

1. INTRODUCTION

NEPTUNE is a collaborative project involving two leading UK Water Service Providers (WSPs) (Yorkshire Water Services and United Utilities), a major provider of automation technologies (ABB) and seven UK universities (Universities of Cambridge, De Montfort, Exeter, Lancaster, Leicester, Sheffield and Imperial College). The aim of NEPTUNE is to advance knowledge and understanding about water supply systems in order to develop novel, robust, practical techniques and tools to optimise, via dynamic control or otherwise, efficiency and customer service.

Key needs, identified by the industrial partners, to be addressed in project Neptune are:

- Delivering an optimised water distribution system
- Reacting to an incident before any impact on the customer
- Optimise the decision making process – react to *real* alarms and incidents
- Develop power harvesting techniques
- Support the continued drive to reduce leakage
- Develop innovation in pressure management to deliver key leakage and energy savings e.g. automated control and adjustment
- Build an integrated management system which will monitor leakage, energy, alarms etc
- Develop online models to simulate the distribution network into the next 24 hours
- Provide options to make significant savings in energy e.g. through pump schedule optimisation

The project is structured into 3 main Research Priority Areas (RPA) each of which has sub-work packages, plus the “Integrating Work Package”. The project members use the Harrogate and Dales area of the Yorkshire Water system to test and demonstrate new technologies developed in the NEPTUNE project (Figure 1).

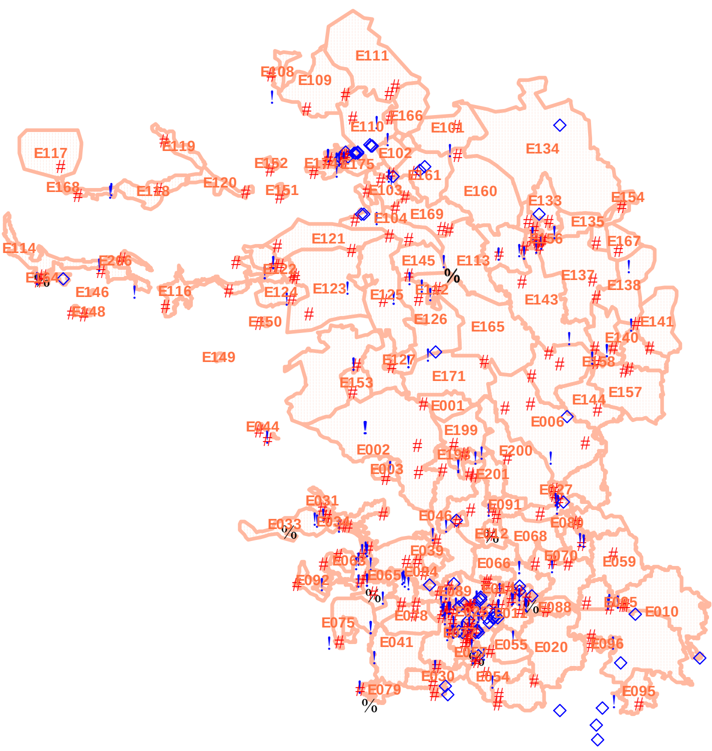

Figure 1. Map of Harrogate and Dales region showing DMA boundaries and locations of flow and pressure (red circles) and pressure only (blue squares) instruments

2. DATA AND KNOWLEDGE MANAGEMENT

The overall aim of RPA1 is to develop pragmatic, robust and novel methods and technologies to understand system performance in real time and will provide the framework and details for data capture and analysis and interpretation, turning data into information. Specific objectives to meet this aim are:

a) Communication network: To evaluate and test the functionality and reliability of existing sensors and hardware for remote data collection.
b) Sustainable Technology: To develop power use and harvesting technologies that will permit a reduction in energy usage or negate the need for regular battery replacement and provide potential to improve sampling frequencies as required/necessary.
c) Real Time Information: To gain knowledge of the performance of distribution networks in near real time, automated online analysis.
d) Optimal Operations: To improve the interpretation, understanding and knowledge of the performance of the distribution network, e.g. by combining appropriate data, including study of temporal and spatial scales of instrumentation and online hydraulic modelling.

The majority of the work in RPA1 is facilitated by and hence based around the initiative taken by Yorkshire Water Services to install some 490 first production prototype GPRS enabled Cello loggers in the Harrogate and Dales district metering area (DMA) zones, attached to flow meters and pressure sensors (Figure 1). These GRPS enabled loggers deployed at such a large scale are unique in the water industry, enabling the communication of fifteen minute resolution pressure and flow data, on a half-hourly basis. This initiative has seen almost immediate benefit in cost savings over manual data collection or per call SMS charge and in particular through the implementation of simple flat line alarms in providing a near real time awareness of major changes in system performance. This deployment of GPRS loggers will continue to quickly deliver a base level of benefit, however there are numerous issues that should be addressed in order to realise the full potential of the infrastructure whilst minimising cost. Hence RPA 1 will evaluate the capabilities of this GPRS logger network and look to advance future performance by asking and investigating questions of the following type:

- What is the capability and suitability of the existing data acquisition and communication systems?
- Can the site power source last longer to reduce visits?
- What new technologies are available that could be deployed?
- How to get the best knowledge and interpretation of system performance from the data?
- How to deal with/resolve a large number of alarms, some of which may be false?
- Are sensors in the correct position and are there enough/too many of them?
- Are the right parameters being measured and at the right frequency?
- Is there a need to have logging and eventually processing of data on site?

Power Management and Harvesting

Power use and battery life are a major concern for Yorkshire Water for the GPRS loggers. The first production prototype GPRS loggers, running at 15 minute data resolution and data transfer every 30 minutes have an estimated battery life of 12 months. Hence there is currently an anticipated need for ongoing annual maintenance visits. Even with the number of loggers currently deployed this has been deemed unacceptable. Power use studies for current and different logging configuration have therefore been investigated by setting up and running a logger ‘test bed’ at Imperial College. Early results of this have found that the dominant power is consumed in GPRS communication, and the power consumption is positively correlated with the sampling rate, and negatively correlated with the signal strength. When the sampling rate is one sample per second, the power consumption rate is about ten times higher than the one sampling per 15 minutes, which means battery life is reduced to about one tenth. On the other hand, reduced signal strength requires increased transmission power due to the power consumption algorithm in the GPRS modem. The deployment environment of the loggers can be complicated and varies significantly, for example, the signal strength in some sites can be as high as -51dBm while in some other sites, it can be as low as -107dBm. For reliable communication, -97dBm is normally required. The environmental factors that affect the signal strength include distance, surroundings, weather, etc.

In addition to work around the performance of the current technology, Cambridge University have undertaken studies to investigate the potential for small scale, local power generation. The intention of this was not to develop any new devices, but to explore the transfer and application of existing technologies. Six main sources were identified and initially investigated: traffic-induced vibration, temperature difference between water pipes and their environments, flow inside water pipes, pressure fluctuations inside the pipe, solar and wind. Solar and wind have previously been explored by the industrial partners, including small scale application, and were discounted primarily on the basis of vulnerability to vandalism. Figure 2 shows three existing technologies identified under some remaining categories.

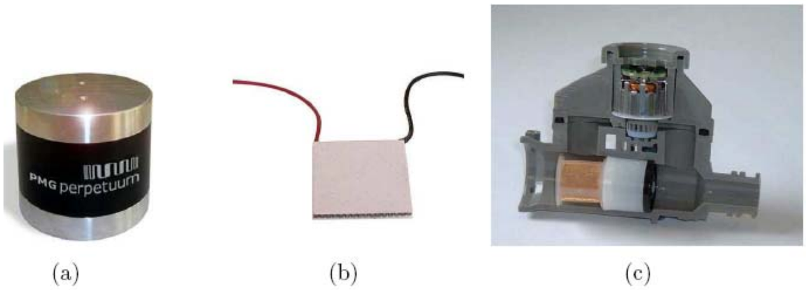

Figure 2. Identified power harvesting technologies (a) Perpetuum harvester (http://www.perpetuum.co.uk/), (b) thermoelectric device (http://www.thermoelectric.com/) and (c) Kinetron microturbine (http://www.kinetron.nl/)

A combination of field, laboratory and theoretical analysis has been undertaken to evaluate these technologies. Theoretical analysis suggested that micro turbines could potentially produce the power required, however laboratory studies have found that sufficient flow can only be generated by running to waste or by generating additional head loss in the pipes line, which would generally be unacceptable. Hence micro turbines have currently been discounted. The results from theoretical modelling, using Lua and finite element method magnetic (FEMM) have indicated that traffic induced vibration has the capacity to deliver the power required. Initial studies have also indicated that temperature differential produced by the thermoelectric device can potentially generate the power required. Theoretical study on mass movement by dynamic pressure fluctuation has been currently conducted. Additionally use of the head difference (“energy loss”) in Pressure Reducing Valves (PRVs) for power harvesting will be analysed as well.

Communication Network

The communication performance of the current GPRS technology has being analysed by Imperial College, and a visualisation application developed. Both spatial and temporal information are jointly presented for quick evaluation of the connectivity status of the whole communication network. Each logger has an individual view to provide the associated GIS information, logger status and time series in graph. This platform not only provides real-time visualisation intelligence, but online signal processing technology can also be associated to process the data in the background. Figure 3 shows a top level view of this visualisation tool for the complete Harrogate and Dales region. Such information, evaluating the performance of the communication networks will be one of the information inputs utilised by the DSS (RPA3).

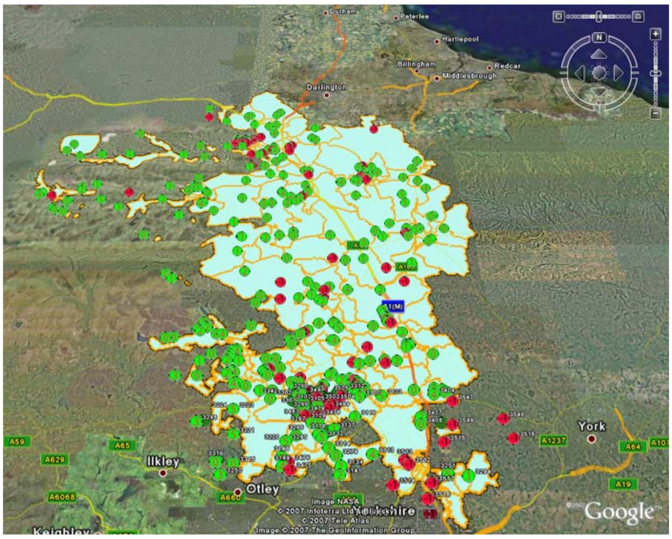

Figure 3. Google earth overlay of GPRS communication performance

Information from Data

Previous work (Mounce, 2005) indicated that the flow signals contained richer information pertaining to system performance than pressure data, hence initial analysis has focused on analysis of flow data. Cambridge University have explored new analysis approaches utilising statistical techniques, deriving a system based on auto-regression and Kalman filtering, while the University of Sheffield have developed the framework to enable integration and online application of previously developed techniques based on artificial intelligence (AI), principally artificial neural networks and fuzzy logic. Off line comparison of the two systems, using control datasets, has indicated that for flow signals the AI technique is superior at detecting medium to large abnormal events as they occur and is hence appropriate for online application, while the statistically based technique has the potential to identify small abnormal events and to better understand the precursor signal to a burst event which characterises long duration slow volume leakage and provides the potential for an early warning of system failure. Hence the two techniques are complimentary. Initial interaction with Yorkshire Water's control room for online application of the AI system has indicated that it also compliments the existing flat line functionality. Appropriately set flat line alarms provide excellent response time to very large events, while the AI system provides a good balance between detection of medium to large events, timeliness of alarms and low number of spurious alerts.

Optimal Instrumentation Studies

Theoretical analysis for the identification of optimal instrumentation location for detection of events as they occur has commenced at the University of Sheffield. This is making use of hydraulic analysis / simulation following previous research into instrumentation location and number studies, such pressure sensors for model calibration (Kapelan *et al.* 2005) and contaminant warning systems ('The Battle of the Water Sensor Networks' Ostfeld et al., 2008). This analysis has already demonstrated that the current UK industry standard 'critical' or 'DG' (usually point of highest elevation) monitoring point can be improved on for event detection. The technique will be extended to facilitate multi-criteria searches to balance the trade off between ability to detect events and the number of instruments. The method has also demonstrated the theoretically ability to localise events within DMAs through strategic deployment of a relatively low number of instruments and development of simple rules for correlation of responses. A key stage in demonstrating this work will be the linkage of the hydraulic simulations with the variability of real systems / data and the capabilities of the event detection algorithms being developed.

Additionally work has been initiated that will test the possibilities of the existing electromagnetic flow meters to be upgraded to higher sampling frequency mode so that they could used in identifying problems related to fast changes in the system' hydrodynamics. If this turns out to be possible (avoiding thus the costs of dismounting the existing meters and furnishing the new ones) that would be a source of the new information on system's dynamics. Dynamics component of the signal was traditionally considered as a "nuisance" and would normally be filtered out (see Figure 4) whereas here it can serve as a useful new source of data that can generate useful source of information.

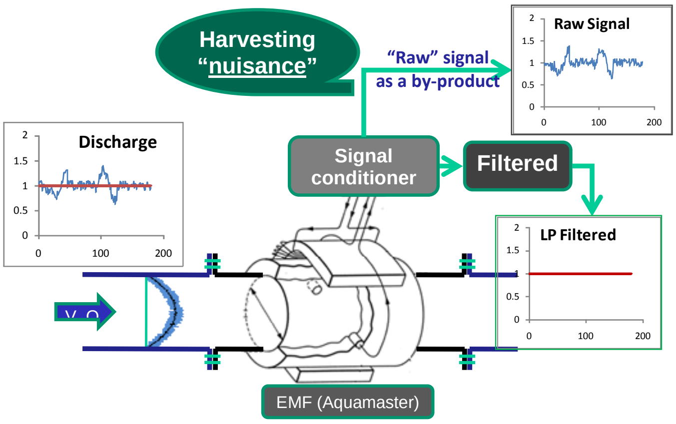

Figure 4. Possible upgrade of the data acquisition of the local signal processing component of an electromagnetic flow meter

Further Work

In the area of power harvesting work is now progressing for field measurements of vibration, to investigate more fully the expected influence of the local location of the chamber relative to the road, traffic loading and design specifics of the individual chambers. Temperature data is being collected from historic studies together with new measurements to particularly evaluate the duration of expected seasonal periods when temperature differentials are low, and difference in the differentials provided by surface and ground water sourced systems.

Work in the area of evaluation of the communication networks will continue and the visualisation tools will be provided for evaluation by RPA3 for DSS as well to the control room as an early deliverable providing additional previously unavailable information.

Considerable work has been undertaken to understand the complex network of Harrogate and Dales system with a view to future development of a system knowledge base which will in part be populated from an online hydraulic model, regularly updated and driven by all the available flow, pressure, reservoir level, pump status etc. data. This online hydraulic model will utilise existing functionality available in the Aquis software provided by 7 Technologies (the software used by Yorkshire Water Services) to, for the first time, provide an online model at significant scale and complexity. The alarms and alerts produced by the statistical, AI, online model and system knowledge base will form the major component of the new information generated from NEPTUNE to inform the DSS (RPA 3).

A major future component of work associated with RPA 1 are studies for verification, validation and practical demonstration of the tools, techniques and technologies being developed. In order to facilitate this, a first 'over sampled' DMA has been established. Current programme aims at collecting more data (by "over-sampling") than what will be available in the future systems in order to identify the needs of these (future) systems, so that they can be optimised i.e. appropriately designed. Future plans will include the possibility of 'engineered' events, assuming that suitable events do not occur naturally within a suitable time frame, and progression through other DMAs moving from an over instrumented and sampled situation towards an optimum state for derivation of performance information.

3. PRESSURE MANAGEMENT

The overall aim of this research area is to: *develop a novel approach and practical tools for pressure and energy management in order to improve customer service, efficiency and sustainability of water distribution systems.*

UK water systems are typically structured into a production part, which includes sources and water treatment works together with a grid of major pipes, service reservoirs and pumps, and a distribution part, which is decomposed into DMAs, each consisting of a few thousand properties. A single inlet DMA controlled by a pressure reducing valve (PRV) is preferred because it is easy to implement and easy to understand by system operators. Nevertheless, there is considerable room for improvement and in this research we will address a number of unresolved theoretical and practical issues:

- The decomposition of a distribution system into DMAs in order to optimise technical and economic criteria (zoning and rezoning)
- The investigation of steady state and dynamic (transient) properties of water systems under PRV control and the development of new electronic and hydraulic controllers to improve system performance
- The combination of pump scheduling with pressure control
- The development of a burst identification method based on active identification experiments.

The zoning research will develop methods and software to define optimal zones for pressure management using evolutionary algorithms. A new improved pressure zoning cost model has been developed and tested on Yorkshire Water case studies (Awad et al., 2008). The software currently being developed assumes a two (day/night) PRV setting. An important part of the approach is to develop methods for 'pressure equalisation' by optimally reducing hydraulic losses within a zone, thereby increasing pressure at critical points at peak demand times and enabling greater pressure management to be applied across the zone as a whole. The software created will be mainly used for planning work but potentially it could also be used operationally for temporary re-zoning to reduce risks in contingency situations.

Steady state pressure control is comparatively well researched but the dynamical behaviour of water systems under PRV control is not well understood. Outlet pressure from a standard PRV with a spring loaded pilot valve can fluctuate randomly by ±2m around a set-point due to changes in demands and the switching of pumps or other control components. The deviation of the outlet pressure can be significantly reduced by replacing the pilot valve with new electronic or hydraulic controllers. Two electronic controllers have been proposed and investigated, one is PID-based and uses only pressure measurements and the second uses the outlet pressure and flow measurements. Modelling studies have confirmed that both controllers can reduce the outlet pressure deviation tenfold. At the moment implementation of such controllers may be not practical as they require power supplies and regular maintenance. The preferred option for water companies is a hydraulic controller such as the Aqui-Mod controller from Aquavent (Peterborough, UK). The properties of this controller are being analysed in a test rig and field environment. The aim of this research is to propose changes to the hydraulic controller to provide deviation attenuation which is comparable to that achieved by electronic controllers.

A PRV set-point can be controlled by a time schedule (a time modulated PRV) which follows changes in demands or by a feedback from the PRV flow (flow modulation PRV). The research challenges are the calculation of optimal flow modulation curves, the control of a DMA with many inlets and the coordinated pressure control of many interacting DMAs. Theory and simulation studies have been completed and will be field tested on case studies provided by Yorkshire Water Services (YWS).

Normally, the energy management task, which is concerned with scheduling grid pumps, and the pressure control task, which is concerned with scheduling PRV set-points, are considered separately. This leads to a situation in which powerful pumps generate unnecessarily high head, which is subsequently throttled by PRVs with significant energy wastage. Many modern pumps are equipped with variable speed drives since manipulating speed is a very efficient method of reducing energy use - the power consumption changes with the cube of the speed. The proposed approach here is based on nonlinear mixed-integer programming where decision variables includes pump controls (on/off), pump speeds (continuous variables) and PRV set-points (continuous variables). The next stage of the research is to investigate the feasibility of synthesising continuous feedback from reservoir levels to pump and valve operation taking into account the operational constraints and the electrical tariff. This can be viewed as a generalisation of a simple practical rule where a pump is controlled by the level of an associated reservoir, e.g. 'if the tank is full switch the pump OFF, if the tank is empty switch the pump ON'. The methodology relies on preparing a control law in an off-line mode which is subsequently used in a real time situation. The implementation of the scheduling software is at an advanced stage and the test case studies are provided by Yorkshire Water Services (YWS) and United Utilities (UU).

The burst identification procedure can be based on the use of measurements during normal operating conditions (passive identification) or on active identification experiments. The passive identification approach is described in the section on Data and Knowledge Management whilst here an active identification procedure for pin-pointing the burst locations is being developed. The method involves changing PRV outlet pressure and monitoring boundary and internal DMA variables followed by the enhanced modelling of pressure dependent leakage components. The accuracy of the burst localisation depends on the number of available measurements inside a DMA. The software supporting the identification procedure is being developed in Matlab and will be tested later in the year on the case studies provided by the industrial partners.

4. RISK-BASED DECISION SUPPORT

Introduction

The aim of RPA3 is to develop an integrated, risk-based decision support system (DSS) for evaluation of intervention strategies to inform decision making for sustainable water system operation. The research work in RPA3 is divided into the following four work packages:

1. <u>WP 3.1 DSS Framework Development.</u> The aim of this WP is to develop an integrated, risk-based, decision-support framework to support tactical (real-time) and strategic decision making. More specifically, the objectives are: (a) to develop a conceptual framework for the implementation of a DSS capable of supporting complex decision making to improve the operation of water supply systems; (b) to develop a specification for the software engine that underpins the DSS and coordinates asynchronous and real-time interaction between functional modules that can be combined to constitute the NEPTUNE DSS and (c) to develop and test the software engine, application programming interfaces and generic subsystems of the DSS framework.

2. WP 3.2 Models and Knowledge Components. The aim of this WP is to develop specific DSS knowledge components for applications in real-time and strategic management. The specific objectives are as follows: (a) to establish novel model-based and knowledge-component methodologies to support tactical and strategic decision making for real-time incident and energy management; (b) to investigate the use of data mining and other Artificial Intelligence tools for the development of real-time operating rules and (c) to test and validate model-based and knowledge-component methodologies on test cases provided by the industry collaborators.
3. WP 3.3 Uncertainty, Risk and Robust Decision Methodologies. The aim of this WP is to develop a new general methodology for the management of risk and uncertainty associated with the decision making process for water supply networks. The specific objectives are as follows: (a) to investigate and develop a new methodology for the management of risk and uncertainty associated with the decision making process; (b) to develop optioneering type methodology to evaluate and recommend robust (risk/uncertainty insensitive) intervention strategies for control/mitigation of risk associated with incidents.
4. WP 3.4 DSS Prototype Development and Implementation. The objective is to develop, test and validate a prototype DSS on a case study area (Harrogate Dales area in Yorkshire, England).

DSS Framework

The DSS Framework designed as part of RPA3 seeks to design a conceptual framework for the implementation of a DSS capable of supporting complex decision making to improve the operation of water supply and distribution systems. It furthermore attempts to develop a specification for the software engine that underpins the DSS and coordinates asynchronous and real-time interaction between functional modules that can be combined to constitute the NEPTUNE DSS so as to: (1) provide maximum flexibility to academic partners for development/research, (2) provide maximum benefit for industrial partners, (3) facilitate the delivery of an integrated prototype application, (4) employ a design-led approach driven by the needs of operators, (5) be based upon sound industrial experience and (6) optimise development time and resources.

DSS Software Implementation

Current programming techniques focus on producing maximally reusable code to facilitate development of other related projects. To follow these trends, several design patterns were implemented to increase the reusability of the code and extensibility of the application, which was one of the main goals. Frequently applications combine business logic with user interface and control logic. For small projects, this approach saves some time during the development but it creates code that is not reusable and modification to one of the layers requires changes to the others. This simple approach brings great problems for large applications and therefore layered architecture known as Model-View-Controller (MVC) has been proposed. The MVC architecture was first used in Smalltalk (Ingalls, 1976) and gave rise to many subsequent framework implementations. The architecture defines following three layers: (1) Model: represents the business logic of the application (e.g. computational engines); (2) View: represents presentation layer (user interface) of the application to display results produced by its model; (3) Control: is generally responsible for accepting and processing requests from clients (normally users) passing the requests to the models and instructing the graphical user interface (GUI) to display the results according to a predefined workflow. The interactions between the components forming the MVC can be seen in Figure 5.

The application of these three tiers of system implementation, with respect to the NEPTUNE DSS, is described in the following sections. An overview of the proposed Framework implementation may be seen in
Figure **6**.

View Layer

The topmost layer of the application is responsible for the interaction with the end user and the presentation of results. The key characteristic of View layer Modules is that they are inherently passive – in that, they do not respond to actions, as such, rather they utilize data exposed by the Control layer. The proposed framework adopts a two-screen approach to present the control environment to the operator as seen in Figure 7. The first (Master) screen is the domain of the 800xA environment supplied by ABB in which the current state of the network is displayed and alarm conditions monitored. The second (Slave) screen presents the Neptune-project specific outputs generated by the RPA3 framework and associated tools. These two screens are described in the following sections.

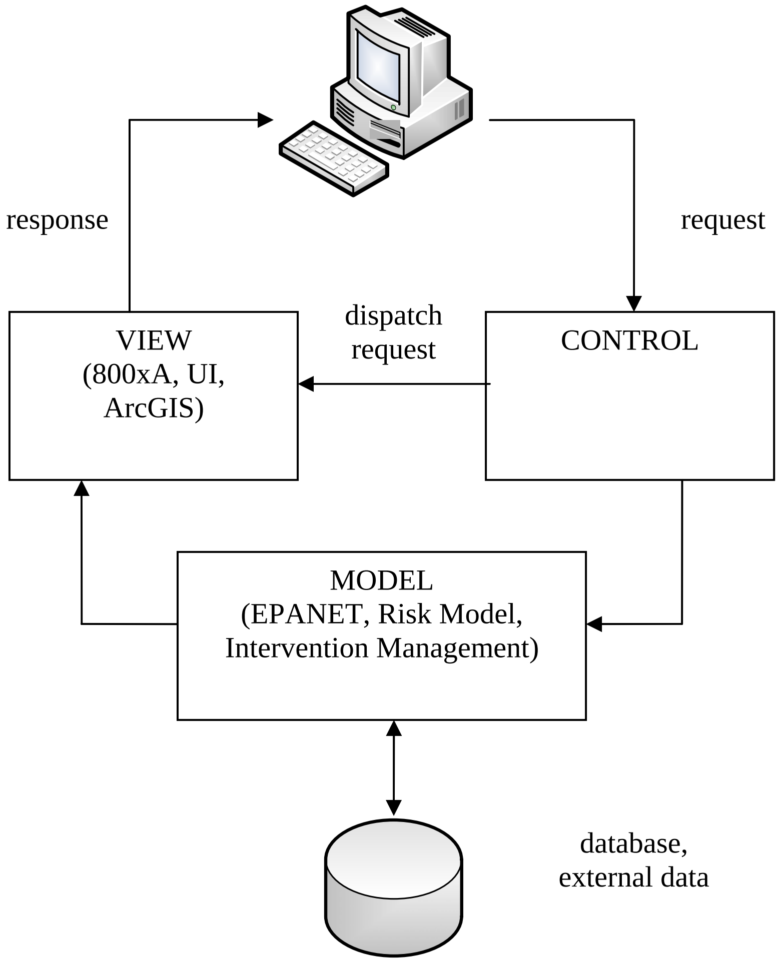

Figure 5. Model-View-Control Architecture overview

Master Screen Interface. The left-hand side of Figure 7 proposes a general overview of an implementation of the Master Screen (800xA) interface. Its key constituents are: (1) A hierarchical navigator for drilling down through the constituents of the distribution system; (2) trend displays; (3) alarm lists. From the perspective of the RPA3 DSS framework, the key functionality required of the 800xA side of the *View* tier is the ability to launch the investigation of one of the alarm conditions or the evaluation of a what-if scenario based on information such as pumping schedule changes proposed by RPA2. This is achieved through the use of an aspect associated with the alarm conditions which triggers an HTTP request to investigate that alarm condition or what-if scenario.

Slave screen interface. The Slave screen (shown in the right-hand part of Figure 7) is used for investigation into and visualisation of the risk associated with incidents. Visualisations encompass facilities such as geographic information system (GIS) maps, charts, 3D rendering etc. and access data exposed, particularly by Data Analysts, for display. Currently, the visualisations implemented include a GIS window, which is used to provide a graphical display of a network model with thematic mapping capabilities as well a basic charting Module, which can be use for displaying result comparisons. Visualisation process will employ several techniques. GIS will be used to display the risk of Alarms, Alerts and Reports (AARs) in the form of "risk maps". The operator will also be given the opportunity to display risk maps for particular incidents being part of a set belonging to an AAR. An "alarm list" (e.g. a table) will also be used to present information (including risk probability and consequences) in a textual form, so that the operator has an overview of current situation in the network even while inspecting a potential incident within particular DMA. Risk maps will be the core visualisation technique to support the risk-based decision making process. A risk map will be used to present the risk of an alarm and consequently the risk of a particular incident to the operator. The risk will be presented as a split metric of probability and consequence thus allowing the operator to capture also rather rare incidents having disastrous impact on the customers. The risk map will be presented in GIS and thus provide the operator with spatial distribution of risk in the region of interest thus allowing him to send field technicians to the areas with high-risk density. An example of a possible risk map is given in Figure 7.

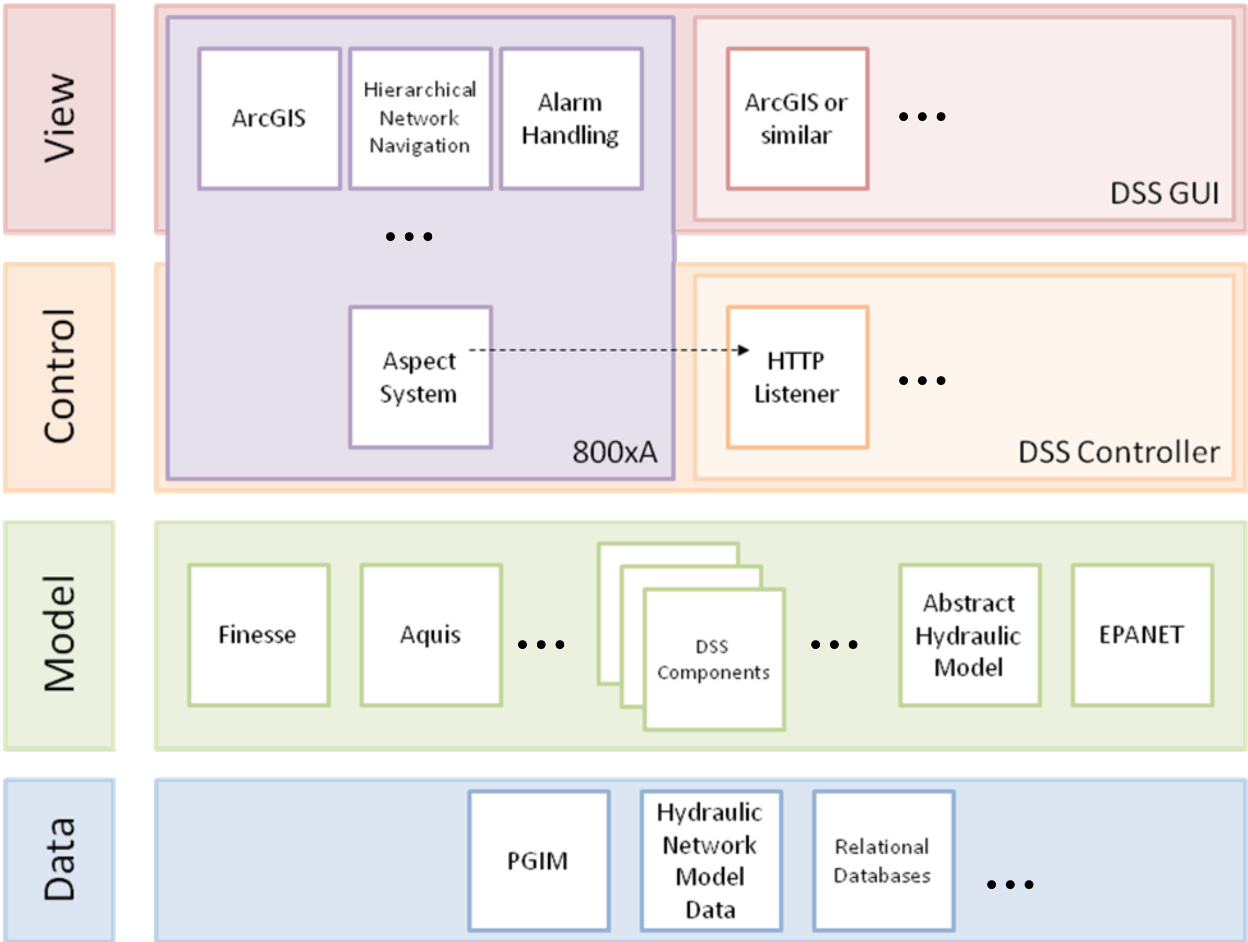

Figure 6. Overview of DSS Framework Implementation using MVC paradigm

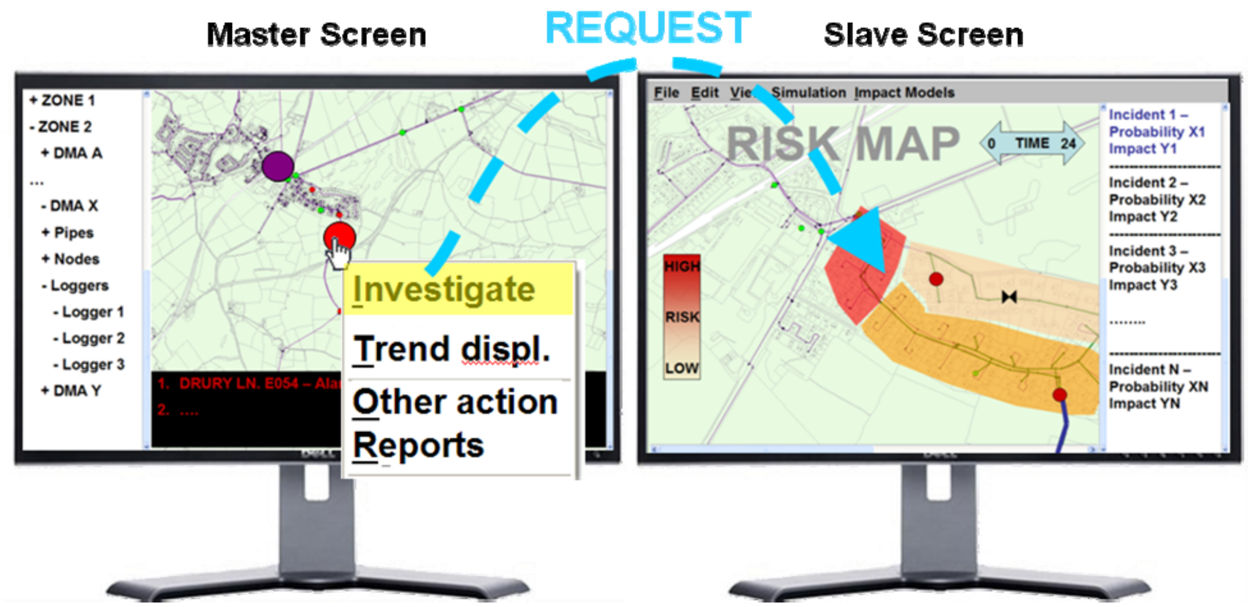

Figure 7. Twin screen arrangement for NEPTUNE DSS

Control Layer

The Control Layer is responsible for the functional operation of the Decision Support Tool. Despite appearances in the View Layer, the Control Layer implements all but the most basic functionality of the application. This distinction is vital as it allows for a high-degree of independence between the View and Control Layers allowing for the efficient replacement and variation of user interfaces. Whilst the View Layer might be responsible, for example, for the processing of menu selections, the Control Layer will ultimately determine what action that selection performs. In the context of the RPA3 DSS, the control module is tasked not only with the applying the responses to user input but also with responding to the initial request from the 800xA side of the DSS for the investigation of incidents or the presentation of further details of other outputs produced by tools in the DSS.

Model Layer

The Model Layer comprises the information upon which the Decision Support System Tool acts and the processes that it employs undertake this analysis. These data may be in many forms: external database connections, spatial data and temporally variable data.

Further Work Planned

Following the development of the DSS framework, research is now focusing on the development of individual modules (including for example the Incident Risk Estimator and the Intervention Manager, also discussed in Bicik et al., 2008). The modules implement novel risk-based methodologies and algorithms with an emphasis on real-time operations and decision support. This emphasis, however, introduces new challenges in terms of strict time constraints on computational time, dynamically changing states of the network and its supervisor control system, and other uncertainties stemming (inter alia) from gaps in our knowledge of the system and its operation in real time. The situation is further complicated by the need for the integration of data coming from several independently operated systems (e.g. sensors, GIS, trend databases, hydraulic models, etc.). The proposed DSS addresses a series of these challenges, by supporting the operator to prioritise both investigative and intervention actions using dynamically changing information about potential incidents. It generates and filters alarms in a more intelligent way, partially automating the process of investigation by mimicking the behaviour of an operator - while taking into account the potential risks associated with an alarm and the uncertainties about the state of the system.

5. INTEGRATING WORK PACKAGE

The IWP has a coordinating role, is looking at operator behaviour and expectations at a high level and is intended to glean new information from Neptune as a whole. The work has so far concentrated on the operators and decision makers and contextual aspects of operations and the psychology of human-machine interaction. The crucial processes are those located within such interactions which help develop the intelligibility of action and behavioural responses. Computers and the action which humans take can only be understood by considering "the 'situations' in which it occurs" (Heath and Luff, 2000). It is not the 'person solo' who takes action, but the 'person plus' amid a whole system of interrelated factors as "every course of action depends in essential ways upon its material and social circumstances" (Suchman, 1987). Neptune is investigating how particular circumstances affect humans' behaviours and how such contexts may be used to achieve 'intelligent action' and attain desired outcomes in investigations of human-computer-interaction (HCI) with the key partners in the project. The research takes a qualitative approach founded in an 'interpretivist' position to attempt to capture rich detail about how humans interact with computers and how this interaction constructs their actions (Mason, 2002). This has used two qualitative data collection methods; qualitative interviews and a qualitative questionnaire. Via four interviews within two water companies at two separate levels of the organisational chain. Interviews were conducted at the plant operator/ control room operator level and the level of the field technician/ operator. These two levels were addressed to allow the study to explore different interactions with machines with differences in environments, uses of data and henceforth situated actions. Initially semi-structured interviews were deemed appropriate for data collection from software developers but geographical location and financial constraints did not permit this method and a questionnaire was developed.

In the initial phase of the project, interviews with YWS and UU have shown that process knowledge from employees does not appear to be well captured by the organisations. This is predominantly held within the heads of employees, resulting in the organisations commonly being highly dependent on the availability and retention of particular employees. These key employees are known as 'experts' in certain matters and geographical areas. It is clear that each organisation wishes for process knowledge to be better shared, enabling a better coordination of work activities and reducing the dependence on particular employees.

As the working culture in each organisation is to utilise these experts, it is concluded that the organisations involved consider new ways in which the experts can help in both the immediate and the longer term using better technology. Computers can and are already supporting both the interaction of 'experts' and their work colleagues in situations whereby the knowledge of experts needs to be instantly applied and for the longer term dissipation of knowledge.

Technology such as real-time messaging on Toughbooks and two-way video calling are some of the new ways in which employees may utilise technology to interact with experts to help immediate situations. Two-way video calling enables employees' face to face interaction with experts and allows employees to present the situation at hand visually. Real-time messaging may be useful on occasions where talking on the telephone would be difficult or where messaging would simply be the preferable communication medium.

Computers may also aid the longer term dissipation of experts' process knowledge. Interviewees noted that some form of knowledge database whereby knowledge could be easily input and read by relevant colleagues would be a valuable asset. The internet or the intranet of the organisations provide good foundations for software programs to be remotely hosted permitting multiple accesses at multiple locations. Furthering this idea all employees could be invited to participate in discussion forums on the intranet, internet or extranet. Such forums may be grouped by subject area and may include topics of a non-work related nature.

Successful construction and utilisation of any such knowledge repositories, however, will require incentives for employees to share their knowledge and access such a system. Employees commonly would not wish to disclose their process knowledge due to the effort required to enter their knowledge and the fact that such sharing may deem themselves less valuable to the organisation. As such organisations must ensure that personal incentives or aligned with those of the organisation and group productivity (Olson and Olson, 2003).

6. SUMMARY AND CONCLUSIONS

The project NEPTUNE seeks to address the knowledge gap that exist between theory and practice of developing and using new technologies required to fully understand, manage and automate water supply system operation. The project is structured into 3 main RPAs plus the "Integrating Work Package". The project uses the Harrogate and Dales area of the Yorkshire Water system to test and demonstrate new technologies developed.

RPA1 objectives are: a) to evaluate and test the functionality and reliability of existing sensors and hardware; b) to develop power use and harvesting technologies that will permit a reduction in energy usage or negate the need for regular battery replacement; c) to gain knowledge of the performance of distribution networks in near real time, automated online analysis; and d) to improve the interpretation, understanding and knowledge of the performance of the distribution network.

Early results of power use have found that the dominant power is consumed in GPRS communication. Although initial theoretical analysis suggested that micro turbines could potentially produce the power required, laboratory studies have found that sufficient flow cannot be generated in normal situations. The preliminary results from theoretical modelling have indicated that traffic induced vibration has the capacity to deliver the power required. Studies have also indicated that temperature differential produced by the thermoelectric device can potentially generate the power required. Further work is ongoing to evaluate the potential of other power harvesting technologies.

An artificial intelligence based approach, suitable for online use, for identification of medium to large leak/burst events as they occur has been identified and found to be complementary to existing flat line alarm functionality. Additionally a statistically based system capable of capturing the progressive development of smaller, background, leaks has been developed. Theoretical analysis for the identification of optimal instrumentation location for detection of events as they occur has demonstrated that the current UK industry standard 'critical' or 'DG' (usually point of highest elevation) monitoring point can be improved on for event detection. The technique will be extended to facilitate multi-criteria searches to balance the trade off between ability to detect events and the number of instruments. The method has also demonstrated the theoretical ability to localise events within DMAs through strategic deployment of a relatively low number of instruments and development of simple rules for correlation of responses.

The overall aim of RPA2 is to develop a novel approach and practical tools for pressure and energy management. RPA2 research objectives are: a) to decompose a distribution system into DMAs to optimise technical and economic criteria (zoning and rezoning); b) to investigate steady state and dynamic (transient) properties of water systems under PRV control and to develop new electronic and hydraulic controllers to improve system performance; (c) to combine pump scheduling with pressure control; and (d) to develop a burst identification method based on active identification experiments.

The zoning research will develop methods and software to define optimal zones for pressure management using evolutionary algorithms. A new improved pressure zoning cost model has been developed and tested on Yorkshire Water case studies. Even though the results obtained cannot be generalised, they clearly demonstrate the importance of the estimation of a number of different benefits and costs related to zoning and pressure management. This seems to apply particularly to the net benefits associated with burst frequency reduction, pressure-sensitive demand reduction and customer contacts reduction

The dynamical behaviour of water systems under PRV control is generally not well understood. Outlet pressure from a standard PRV with a spring loaded pilot valve can fluctuate randomly by ±2m around a set-point, but this deviation can be significantly reduced by replacing the pilot valve with new electronic or hydraulic controllers. Two electronic controllers have been proposed and investigated, one is PID-based and uses only pressure measurements and the second uses the outlet pressure and flow measurements. Modelling studies have confirmed that both controllers can reduce the outlet pressure deviation tenfold.

The proposed approach to energy management is based on nonlinear mixed-integer programming where decision variables includes pump controls (on/off), pump speeds (continuous variables) and PRV set-points (continuous variables). The next stage of the research is to investigate the feasibility of synthesising continuous feedback from reservoir levels to pump and valve operation taking into account the operational constraints and the electrical tariff. This can be viewed as a generalisation of a simple practical rule where a pump is controlled by the level of an associated reservoir

The aim of RPA3 is to develop an integrated, risk-based decision support system (DSS) for evaluation of intervention strategies to inform decision making for sustainable water system operation. The research work in RPA3 is divided into four areas: (a) DSS framework development; (b) development of models and knowledge components; (c) development of uncertainty, risk and robust decision methodologies; and (d) DSS prototype development and implementation.

The new DSS framework provides a specification for the software engine that underpins the DSS and coordinates asynchronous and real-time interaction between functional modules to: (1) provide maximum flexibility to academic partners for development/research, (2) provide maximum benefit for industrial partners, (3) facilitate the delivery of an integrated prototype application, (4) employ a design-led approach driven by the needs of operators, (5) be based upon sound industrial experience and (6) optimise development time and resources. The software architecture adopts the Model-View-Control approach where ‘Model’ represents the business logic of the application (e.g. computational engines); ‘View’ represents presentation layer (user interface) of the application to display results produced by its model; and ‘Control’ is generally responsible for accepting and processing requests from clients (normally users) passing the requests to the models and instructing the GUI to display the results according to a predefined workflow.

Following the development of the DSS framework, research is now focusing on the development of individual modules including for example the Incident Risk Estimator and the Intervention Manager. The modules implement novel risk-based methodologies and algorithms with an emphasis on real-time operations and decision support. This emphasis, however, introduces new challenges in terms of strict time constraints on computational time, dynamically changing states of the network and its supervisor control system, and other uncertainties stemming (inter alia) from gaps in our knowledge of the system and its operation in real time.

The IWP has a coordinating role, is looking at operator behaviour and expectations at a high level and is intended to glean new information from NEPTUNE as a whole. In the initial phase of the project, interviews with YWS and UU have shown that process knowledge from employees does not appear to be well captured by the organisations. As the working culture in each organisation is to utilise these experts, it is concluded that the organisations involved consider new ways in which the experts can help in both the immediate and the longer term using better technology. Computers can and are already supporting both the interaction of 'experts' and their work colleagues in situations whereby the knowledge of experts needs to be instantly applied and for the longer term dissipation of knowledge.

7. ACKNOWLEDGEMENTS

This work is developed within the NEPTUNE research project funded by the UK's Engineering & Physical Science Research Council (EPSRC), grant EP/E003192/1, and Industrial Collaborators.

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